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Dated 11 December 2003

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APPLICATION NO.: New U.S. Application
FILED: December 23, 2003
FOR: AN ELECTROSURGICAL GENERATOR
ATTORNEY DOCKET NO.: 117343

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2. Patent application number *(The Patent Office will fill in this part)*	0300508.9 — 09 JAN 2003
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Gyrus Medical Limited Fortran Road St Mellons Cardiff CF3 0LT United Kingdom
Patents ADP number *(if you know it)*	5809116003
If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4. Title of the invention	An Electrosurgical Generator
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	WITHERS & ROGERS Goldings House 2 Hays Lane London SE1 2HW
Patents ADP number *(if you know it)*	1776001

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Claim*(s)*	4 DML
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DUPLICATE

P510670GB

AN ELECTROSURGICAL GENERATOR

This invention relates to an electrosurgical generator and to an electrosurgery system, in particular a system having a bipolar electrosurgical instrument.

It is known to use an electrosurgical generator to supply a bipolar electrosurgical instrument with pulsed electrosurgical power at very high voltages, e.g. in the region of 1 kilovolt peak-to-peak when removing tissue at an operation site immersed in a conductive liquid, such as saline. The instrument may have an active electrode located at its extreme end to be brought adjacent to or into contact with tissue to be treated, and a return electrode set back from the active electrode and having a fluid contact surface for making an electrical connection with the conductive liquid. To achieve tissue removal, the conductive liquid surrounding the active electrode is vaporised to cause arcing at the electrode. The high voltages used to achieve vaporisation under varying load impedance conditions are particularly demanding of the generator when the instrument experiences a low load impedance. Indeed, under such conditions it is difficult reliably to initiate arcing. Steps have been taken to increase power density at the active electrode and, hence, improve the reliability with which arcing is started, by reducing the size of the electrode and by roughening its surface, e.g. by applying an oxide layer. The latter technique has the effect of trapping vapour in the irregularities in the surface as a means of increasing power density.

It has been found that operation of such instruments at high voltages tends to cause erosion of the active electrode. The rate of erosion increases as the supply voltage is increased, and is also exacerbated by reducing the size of the electrode and providing a roughened surface, as just mentioned.

Published European Patent Application No. EP1053720A1 discloses a generator for generating high electrosurgical voltages.

It is an object of the invention to improve the power density available at the active electrode for vaporisation, whilst reducing electrode erosion.

According to a first aspect of this invention, an electrosurgical generator comprises a source of radio frequency (r.f.) energy, an active output terminal, a return output terminal, a DC isolation capacitance between the source and the active output terminal, and a pulsing circuit for the source, wherein the source and the pulsing circuit are arranged to generate a pulsed r.f. output signal at the output terminals, which signal has a peak current of at least 1A, a simultaneous peak voltage of at least 300V, a modulation rate of between 5Hz and 2kHz, and a pulse length of between 100μs and 5ms.

With such a generator it is possible to start arcing even under conditions of relatively low load impedance. Once an arc is established, the load impedance tends to rise, to the extent that the arcing can be maintained using a continuous r.f. output waveform.

The length of the pulses is preferably between 0.5ms and 5ms, the pulse duty cycle typically being between 1% and 20% and, more preferably, between 2% and 10%.

The preferred generator in accordance with the invention is operable to generate, during at least an initial part of a treatment period, a peak power of at least one kilowatt, and typically at least 3 or 4 kilowatts. Improvements in electrode erosion performance can be achieved by providing means in the generator for limiting the output voltage to a value in the region of 900V to 1100V peak-to-peak.

In the preferred generator, the source and the pulsing circuit are arranged to generate, in an initial period, a pulsed r.f. output signal at the output terminals, which signal has a peak current of at least 1A, a simultaneous peak voltage of at least 300V, a modulation rate of between 5Hz and 2kHz, and a pulse length of between 100μs and 5ms, and, in a subsequent period, to generate a constant power r.f. output signal at the output terminals.

Different ways of causing the generator to end the above-mentioned initial period of operation and begin the so-called subsequent period are feasible. In one generator embodiment, the switchover from the initial period to the subsequent period occurs

automatically at a predetermined time interval after the beginning of the initial period. In an alternative embodiment, the generator has means for monitoring the load impedance between the active and return output terminals, and is arranged to cause switchover to the subsequent period when the magnitude of the output impedance increases by a predetermined factor, typically between 5 and 20, and preferably 10, or when it exceeds a predefined threshold.

The preferred generator uses a third switching-over technique. In this case, the source of r.f. energy includes an r.f. output stage, and the generator has a power supply including a charge-storing element such as a large capacitor for supplying power to the output stage. When the treatment period includes an initial period and a subsequent period, as described above, the capacitor is used to supply power at least during the initial period. Associated with the capacitor is a voltage-sensing circuit for sensing the voltage supplied to the output stage by the capacitor, the generator being arranged such that treatment ends or the subsequent period begins in response to the supply voltage as sensed by the voltage-sensing circuit reaching a predetermined voltage threshold. Indeed, it is possible to control the length and timing of individual pulses using the same voltage-sensing circuit. In this case, the voltage-sensing circuit forms part of the above-mentioned pulsing circuit and the timing of the leading and trailing edges of the pulses produced by the output stage is determined by the supply voltage respectively falling below and exceeding the respective voltage thresholds.

The charge-storing capacitance preferably has a capacity in excess of 5J.

The generator may have a tuned output. Indeed, good results have been obtained using a generator with a resonant output network, the load curve of the generator (i.e. the curve plotting delivered power versus load impedance) having a peak at a load impedance below 50 ohms. Delivery of peak power levels into low load impedances is aided by forming the output network as a series-resonant network comprising the series combination of an inductor and a capacitor, the output to the output terminal of the generator being taken via a coupling capacitor and, optionally, a step-up transformer from a node between the inductor and the capacitor of the series combination. Whilst it

is possible, instead, to take the output from across the inductor, taking it across the capacitor has the advantage of reducing switching transients.

The resonant output network typically provides a source impedance at the output terminals in the range of from 50 ohms to 500 ohms.

Not least because the resonant frequency of the output network can vary with load impedance as a result of coupling capacitance, the r.f. source includes a variable frequency r.f. oscillator, the output frequency advantageously being limited to a maximum value below the resonant frequency of the output network when connected to a matching load impedance, i.e. a load impedance equal to its source impedance.

According to another aspect of the invention, an electrosurgery system comprises a generator having a source of radio frequency (r.f.) energy and, coupled to the generator, a bipolar electrosurgical instrument having an electrode assembly with at least a pair of electrodes, wherein, the generator is adapted to deliver r.f. energy to the electrode assembly in an initial period as a pulse modulated r.f. signal which, in use with the pair of electrodes, has a peak current of at least 1A, a simultaneous peak voltage of at least 300V., a modulation rate of between 5Hz and 2kHz, and a pulse length of between 100μs and 5ms.

The invention has particular application to an electrosurgery system in which the bipolar electrosurgical instrument has an active electrode formed as a U-shaped loop. Such a loop is often used for excising tissue samples but places particular demands on the generator in terms of achieving saline vaporisation and arcing.

The invention will now be described by way of example with reference to the drawings in which:

Figure 1 is a general diagram showing an electrosurgery system in accordance with the invention, including a generator and a bipolar electrosurgical instrument;

Figures 2A and 2B are respectively perspective and side views of a loop electrode assembly forming part of the bipolar instrument shown in Figure 1;

Figure 3 is a schematic diagram of an electrosurgical generator in accordance with the invention; and

Figure 4 is the load curve of the generator of Figure 3.

Referring to Figure 1, a generator 10 has an output socket 10S providing a radio frequency (r.f.) output for an instrument in the form of an endoscope attachment 12 via a connection cord 14. Activation of the generator may be performed from the instrument 12 via a control connection in cord 14 or by means of a footswitch unit 16, as shown, connected separately to the rear of the generator 10 by a footswitch connection cord 18. In the illustrated embodiment, footswitch unit 16 has two footswitches 16A and 18B for selecting a coagulation mode and a cutting mode of the generator respectively. The generator front panel has push buttons 20 and 22 for respectively setting coagulation and cutting power levels, which are indicated in a display 24. Push buttons 26 are provided as an alternative means for selection between coagulation and cutting modes.

The instrument 12 has a detachable loop electrode assembly 28 with a dual electrode structure and intended for use in a saline field. Figures 2A and 2B are enlarged views of the distal end of the electrode assembly 28. At its extreme distal end the assembly has a U-shaped loop electrode 30 depending from a pair of electrode assembly arms 32 which are mounted side-by-side in a clip 34 intended to be snapped onto an endoscope. The loop electrode 30 is an active electrode. Each of the arms 32 is formed as a coaxial cable, the exposed conductive outer shield of which, in each case, forms a return electrode 36. In operation immersed in a saline field, the loop electrode 30 is typically used for excising tissue samples, the electrosurgical voltage developed between the loop electrode 12A and fluid contacting surfaces of the return electrodes 36 promoting vaporisation of the surrounding saline liquid at the loop electrode 30, and arcing through the vapour envelope so formed.

The loop electrode 30 comprises a composite molybdenum rhenium wire with an oxide coating to promote increased impedance in the electrode/fluid interface and, as a result, to increase power density at the surface of the electrode.

The width of the loop is typically in the range of 2.5mm to 4mm and the wire typically has a diameter in the range of 0.20 to 0.35mm.

This loop electrode assembly places particular demands on the generator in terms of starting vaporisation and arc formation.

Efforts to improve the starting of the arc (the "firing up") of this electrode assembly by reducing the wire diameter and forming oxide layers have tended to increase the rate of erosion or resulted in the loop being mechanically flimsy.

The generator will now be described in more detail with reference to Figure 3. The generator has an r.f. source in the form of a voltage controlled oscillator (VCO) 40, a divide-by-two stage 42, a power driver stage 44, which drives an r.f. output stage in the form of a power bridge 46. The power bridge 46 feeds a resonant output network 48 which delivers a generator output signal across output terminals 50.

To bring the frequency of the VCO 40 to the resonant frequency of the output network, the above-described components of the r.f. source are coupled in a phase-locked loop including a phase sensing element 52 coupled between the power bridge 46 and the output network 48 to sense the current phase in the input leads to the output network. This current phase signal is applied to one input of a phase comparator 54, the other input of which receives a signal representative of the output of the VCO 40, derived from the output of the divide-by-two stage 42 via a delay stage 56 which compensates for the delay to the r.f. signal as it passes through the power driver and the power bridge.

The r.f. output stage 46 is supplied from a DC supply rail 58 attached to a large reservoir capacitor 60 which allows large currents to be drawn by the power bridge 46 for short periods of time, i.e. currents significantly larger than the current rating of a

power supply (not shown) connected to the DC supply rail 58. It follows that the voltage on supply rail 58 will fall during the time that a large current is drawn. Such variations in voltage are sensed by a voltage sensing stage 62 coupled to the rail 58. Voltage sensing stage 62 has a control output coupled to a transmission gate 64 in the line 66 coupling the divided-down output of the VCO 40 to the input 44A of the power driver 44.

The arrangement of the voltage sensing stage 62 and the gate 64 is such that when the voltage on supply rail 58 (the voltage supplied to the power bridge 46) drops below a predetermined voltage threshold, the gate 64 is operated to interrupt the signal path between the VCO 40 and the power driver 44. When the supply rail voltage rises again, the gait 64 reverts to its conducting state. This may happen when the voltage rises above the threshold mentioned above, or a second threshold voltage.

A second transmission gate 68, connected in series in the signal line 66 with the voltage-operated gate 64, has a control input connected to the output of a 0.5 second monostable 70 which is triggered by a current sensing element 72 in one of the input leads to the output network 48. These elements act to interrupt the signal line 66 to the power driver for 0.5 seconds when the power bridge output current exceeds a predetermined threshold.

The resonant output network 48 comprises an in-line inductance L with a tank capacitor C_1. The output is taken from across the tank capacitor C_1 (which takes out switching noise) via a first coupling capacitor C_2. This first coupling capacitor C_2 couples to the output (represented by terminals 50) via a step-up matching transformer with a 1: 2 step-up ratio. The secondary rewinding of the transformer couples to the output terminals via a second coupling capacitor C3. In this embodiment, L is about 0.47μH, the tank capacitor is about 10nF and the two coupling capacitors C_2 and C_3 co-operate (one of them via the transformer T) to form a coupling capacitance of about 23nF.

It will be appreciated that when the output terminals 50 are open-circuit, the resonant frequency of the output network is determined by the series combination of L and C_1. When the output terminals 50 are shorted, the resonant frequency is determined by the

series combination of L and the network represented by C_1, C_2, C_3 and T. With the values given, the short circuit resonant frequency is about 0.55 times the open circuit resonant frequency.

One of the features of a series-tuned output stage is that peak power delivery inherently occurs at extremely low and extremely high impedances. Referring to Figure 4, the load curve of a series-tuned network (i.e. the delivered power versus load impedance) at resonance is shown by the dotted curve A. The network 48 has minimum power delivery, which may be regarded as the "matched condition", at a load impedance across the terminals 50 (Figure 3) of about 200 ohms. It will be noted that the part of the curve A which has a negative slope follows a path which is approximately hyperbolic over a major part of its length, which means that this part of the curve is of similar shape to a constant voltage line on the graph of Figure 4.

The applicant has recognised that such a characteristic, when applied to the output stage of an electrosurgical generator, allows output power to be maximised for a given constant voltage limit over a range of load impedances. It has been found that erosion of the active electrode of an electrosurgical instrument operated in a conductive liquid increased markedly when the output voltage rises above a threshold in the region of 900 volts to 1100 volts peak-to-peak. By arranging for the load curve of the output network 48 to follow an approximate constant voltage curve at about 1000 volts peak-to-peak (340 volts rms) the power delivered into a varying load impedance can be close to the maximum theoretically achievable for that voltage.

In effect, over the range of load impedances of importance in so-called "underwater" electrosurgery, the generator can be made to behave as a constant voltage supply. This can be achieved with a matched output impedance much higher than the load impedance presented by the electrode assembly shown in Figure 2A and 2B in the wetted condition, which, for a 4mm loop is in the region of 25 ohms. This translates to a maximum power of about 4.5kW at 340 volts rms.

The actual load curve achieved with the arrangement shown in Figure 3 is shown by curve B in Figure 4. This deviates from the series-tuned curve A at low impedances

owing to imposition of a current limit using current sensing stage 72, monostable 70 and transmission gate 68 (Figure 3). In the present embodiment, the current limit is set at a level of about 13 amps. The actual load curve B also deviates from the inherent series-tuned load curve A towards the lower part of the negative-slope portion of the curve A so that the delivered power follows a continuing negative gradient as the load impedance rises, again mimicking a constant voltage supply. This latter deviation is deliberate inasmuch as extreme power into a very high impedance is undesirable. The reason for this deviation is the movement of the resonant frequency of the output network 48, as described above, coupled with the imposition of a high-frequency limit on the r.f. frequency output as will be described below. The phase comparator 54 compares the current phase at the input to the output network 48, as sensed by the phase sensing circuit 52, with a delayed version of the output of the divide-by-two circuit 42 which, in turn, is fed by the VCO 40. Accordingly, the phase and frequency of the VCO are varied to maintain a constant phase at the input to the output network 48 subject to the upper frequency limit mentioned above. In the absence of other influences, therefore, the output network 48 is maintained in resonance as the load impedance varies.

Given that the free-running frequency of the phase-locked loop is arranged to be its maximum frequency of operation, the locking characteristics of the phase-locked loop are such that it can be brought into a locked condition at the minimum frequency, corresponding to minimum load impedance, sufficiently quickly to achieve resonance in the early part of the output pulse, but not so that the current limit circuit (sensing circuit 72, monostable 70 and gate 68) fails to trip when the current exceeds a predetermined current threshold.

If, now, the output carrier frequency is limited to a value below the frequency of the matched load resonant condition, the delivered power will fall off as the load impedance increases and the resonant frequency correspondingly rises. In fact, the free-run output frequency of the phase locked loop containing the VCO 40 (Figure 3) is designed to be this maximum frequency. This ensures that the output network always represents a higher source impedance than the impedance of the load, which affords over-voltage protection in the event of a short.

Summarising, to achieve optimum resonant frequency, the excitation oscillator (VCO) is phase-locked to the resonant output network. Defining the range of the VCO provides load curve definition in that the delivered output power falls below the theoretical maximum when the output network resonant frequency rises above the maximum frequency of the divided down output of the VCO 40. In other words, a match at high load impedance is prevented by preventing the VCO from generating the higher frequencies necessary for resonance. It also follows that, at high load impedances, the maximum output voltage is controlled by virtue of frequency.

It will be seen from Figure 4 that the delivered output power is in excess of 1kW over a range of load impedances corresponding to a wetted or partly wetted electrode. Once vaporisation and arcing has been initiated, the impedance rises, and the delivered power falls. To maintain the average output power at 200W or less, the output signal is pulsed when the load impedance is low. It will be understood that with a peak power in excess of 4kW, the pulse duty cycle needs to drop to a level in the region of 5% or less. The pulse repetition rate should be between 5Hz and 2kHz, and is preferably at least 10Hz. These figures are chosen in view of the time taken to initiate vaporisation at the electrode surface. This means that the pulses have a maximum length of about 4 or 5ms into a low impedance requiring maximum power. Typically, the pulse length is in the region of 1 to 2ms. While it is not essential, configuring the r.f. output stage of the generator as an amplifier amplifying the output of a signal derived from a separate oscillator, rather than having a self-oscillating output stage, is preferred in order that full peak power can be achieved within the above-stated pulse lengths. (In this embodiment, the output stage 46 is an amplifier configured as a power switching bridge for high efficiency.) Should the VCO fail to operate at a frequency corresponding to resonance of the output network 48, as may happen at the start of each pulse, excessive output currents associated with such a mismatch are prevented since the series-tuned output network is low impedance only at resonance.

Pulsing of the output signal can be performed in a number of ways, including simply pulse modulating with predetermined pulse lengths and pulse repetition rates. In the mode of operation described here, the output is pulsed only during an initial period

from the commencement of treatment, the output signal being a continuous wave (CW) signal thereafter, i.e. generally when vaporisation and arcing have been achieved and the load impedance is in an upper range. The duration of the initial period may be fixed or it may be determined by monitoring the load impedance and terminating the initial period when the impedance exceeds a predetermined value. In the present embodiment, the duration of the initial period and the length and frequency of the pulses are dynamically variable in response to delivered energy, as measured by the supply rail voltage on supply rail 58. As has been explained above, high instantaneous power levels can be achieved only by allowing the output stage 46 to draw current from a charge reservoir, here a large capacitance such as capacitor 60. As charge is drawn from the capacitor 60, the supply rail voltage drops. Between pulses, the supply rail voltage rises again. Accordingly, by using gate 64 alternately to allow and prevent the passage of an r.f. signal along signal line 66 to the power driver 44 according to the relationship between the supply voltage level and a threshold or thresholds set in the voltage sensing circuit 62, the output of the generator can be pulsed to achieve maximum peak delivered power whilst operating within a predetermined average power limit. This equilibrium of power consumption and DC supply voltage is achieved by setting the voltage thresholds so that the r.f. output stage is activated when the supply rail voltage is sufficient to achieve a maximum vaporisation voltage (e.g. 340V rms) and switched off when a lower threshold is reached. The lower threshold defines the maximum energy per pulse and the repetition rate for a given average power level. The initial period referred to above is terminated when the electrode has "fired-up", in other words when vaporisation and arcing have commenced, so that the load impedance rises and the supply rail voltage stays above the switching threshold or thresholds. In this way it is possible to achieve vaporisation of the conductive liquid surrounding the electrode at impedances as low as 20 ohms without unacceptable erosion of the electrode surface.

CLAIMS

1. An electrosurgical generator comprising a source of radio frequency (r.f.) energy, an active output terminal, a return output terminal, a DC isolation capacitance between the source and the active output terminal, and a pulsing circuit for the source, wherein the source and the pulsing circuit are arranged to generate a pulsed r.f. output signal at the output terminals, which signal has a peak current of at least 1A, a simultaneous peak voltage of at least 300V, a modulation rate of between 5Hz and 2kHz, and a pulse length of between 100μs and 5ms.

2. A generator according to claim 1, wherein the pulse length is between 0.5ms and 5ms.

3. A generator according to claim 1 or claim 2, wherein the pulse duty cycle is between 1% and 20%.

4. A generator according to claim 3, wherein the pulse duty cycle is between 2% and 10%.

5. A generator according to any of claims 1 to 4, operable to generate in a 20ohm load a peak power of at least 1kW, the generator having a resonant output network.

6. A generator according to any of claims 1 to 5, having output voltage limiting means limiting the peak output voltage to between 900V and 1100V peak-to-peak.

7. A generator according to any preceding claim, wherein the source and the pulsing circuit are arranged to generate, in an initial period, a pulsed r.f. output signal at the output terminals, which signal has a peak current of at least 1A, a simultaneous peak voltage of at least 300V, a modulation rate of between 5Hz and 2kHz, and a pulse length of between 100μs and 5ms, and, in a subsequent period, to generate a constant power r.f. output signal at the output terminals.

8. A generator according to any preceding claim, wherein the signal has a peak current of at least 3A.

9. A generator according to claim 7 or claim 8 , arranged to cause the said subsequent period to begin at a predetermined time interval after the beginning of the said initial period.

10. A generator according to claim 7 or claim 8, including means for monitoring in use of the generator, the load impedance between the return output terminal and the active output terminal, the generator being arranged to begin the subsequent period when the magnitude of output impedance increases by a factor of 10.

11. A generator according to claim 7 or claim 8, wherein the source of r.f. energy includes an r.f. output stage, and wherein the generator has a power supply stage including a charge-storing element for supplying power to the output stage, and a voltage-sensing circuit for sensing the voltage supplied to the output stage by the charge-storing element, the generator being arranged such that the said subsequent period is begun in response to the supply voltage as sensed by the voltage-sensing circuit reaching a predetermined voltage threshold.

12. A generator according to claim 11, wherein the charge-storing element comprises a capacitance of at least 1000μF, and wherein the capacitance and the voltage-sensing circuit form part of the pulsing circuit, the timing of at least the beginnings of the pulses produced by the output stage during the initial period being determined in response to the said supply voltage reaching the said voltage threshold.

13. A generator according to any preceding claim, including a resonant output network, the generator power versus lead impedance load curve having a peak at a load impedance of less than 50 ohms.

14. A generator according to claim 13, wherein the output network is a series-resonant network comprising an in-line inductance, the output of the network being taken across a capacitance which resonates with the inductance.

15. A generator according to claim 13 or claim 14, wherein the said output network provides a source impedance in the range of from 50 ohms to 500 ohms at the output terminals.

16. A generator according to any of claims 13 to 15, wherein the r.f. source includes a variable frequency r.f. oscillator, the r.f. output frequency of which is limited to a maximum value below that of the resonant output network in its matched load condition.

17. An electrosurgery system comprising a generator having a source of radio frequency (r.f.) energy and, coupled to the generator, a bipolar electrosurgical instrument having an electrode assembly with at least a pair of electrodes, wherein the generator is adapted to deliver r.f. energy to the electrode assembly as a pulse modulated r.f. signal which, in use with the pair of electrodes, has a peak current of at least 1A, a simultaneous peak voltage of at least 300V, a modulation rate of between 5Hz and 2kHz, and a pulse length of between 100μs and 5ms.

18. An electrosurgery system according to claim 17, wherein the generator is adapted to deliver r.f. energy to the electrode assembly, in an initial period, a pulse modulated r.f. signal which, in use with the pair of electrodes, has a peak current of at least 1A, a simultaneous peak voltage of at least 300V, a modulation rate of between 5Hz and 2kHz, and a pulse length of between 100μs and 5ms, and to deliver r.f. energy to the electrode assembly in a subsequent period as a continuous power r.f. signal.

19. An electrosurgery system according to claim 17 or claim 18, wherein the signal has a peak current of at least 3A.

20. An electrosurgery system comprising a generator according to any of claims 1 to 16 and a bipolar electrosurgical instrument having at least an active electrode coupled to the said active output terminal and a return electrode coupled to the said return output terminal.

21. A system according to any of claims 17 to 20, wherein the active electrode is formed as a conductive loop.

22. An electrosurgical generator constructed and arranged substantially as herein described and shown in the drawings.

23. An electrosurgery system constructed and arranged substantially as herein described with reference to the drawings.

ABSTRACT (FIGURE 3)

AN ELECTROSURGICAL GENERATOR

An electrosurgical generator provides an electrosurgical output which consists, initially, of a high voltage pulsed output signal with a peak current of at least 1 amp, preferably at least 3 amps, to achieve vaporisation of a conductive liquid surrounding an electrosurgical instrument electrode operating in a wet field. Once vaporisation has been established, radiofrequency power is supplied continuously. During the initial period, the pulse duty cycle is typically between 2% and 10%, with a pulse modulation rate of between 5Hz and 2kHz. The generator has a series resonant output network (48) which, in combination with a phase-locked loop, provides quasi-constant-voltage output characteristics. Pulsing is preferably dynamically variable in response to load conditions, such as varying load impedance, by controlling the maximum energy per pulse, power being supplied in the initial period from a storage capacitor (60). The generator is capable of supplying at least 1kW peak into a load of 20 ohms in the initial period without excessive electrode erosion.

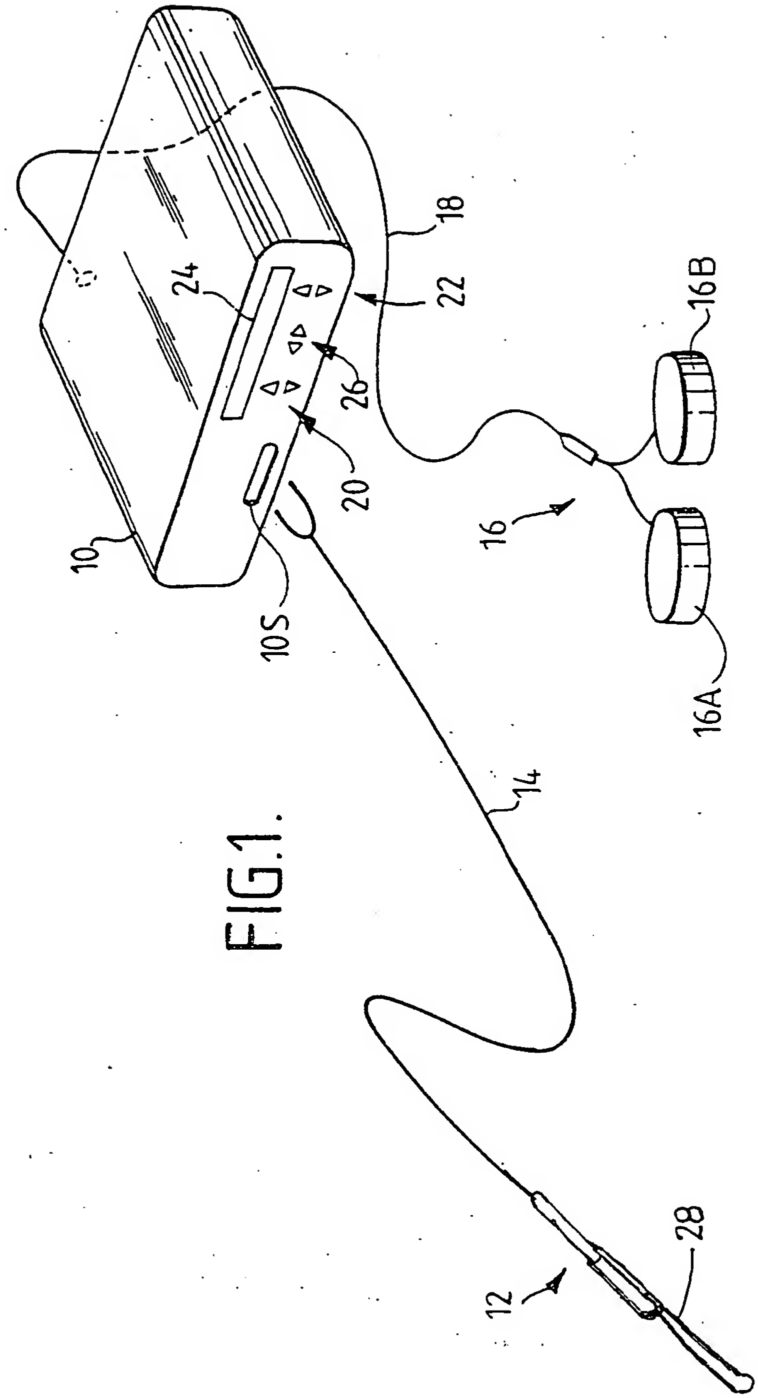

FIG.1.

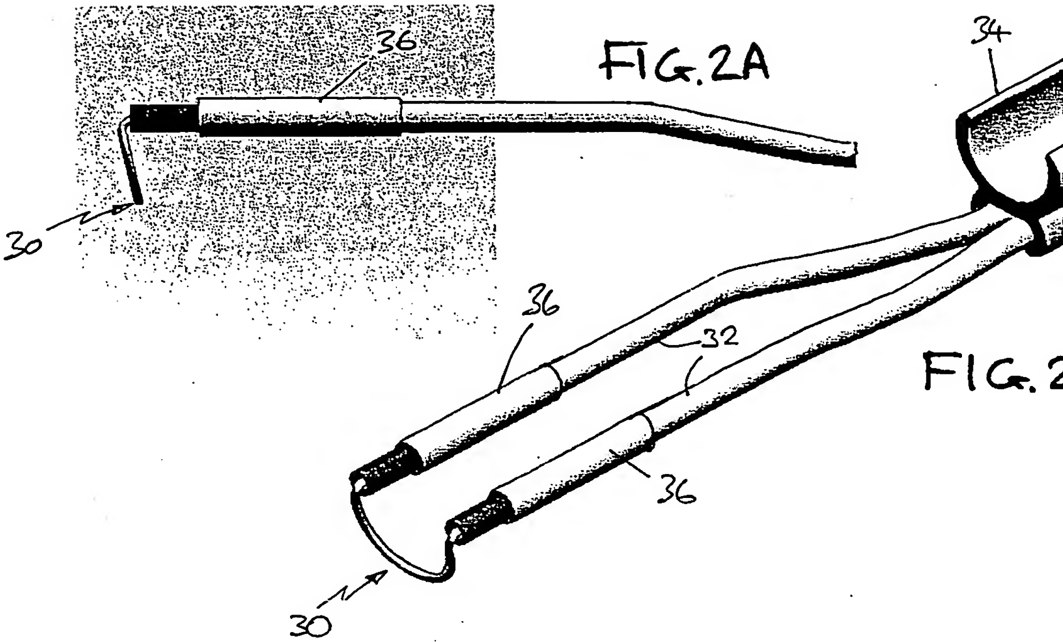

FIG.2A

FIG.2B

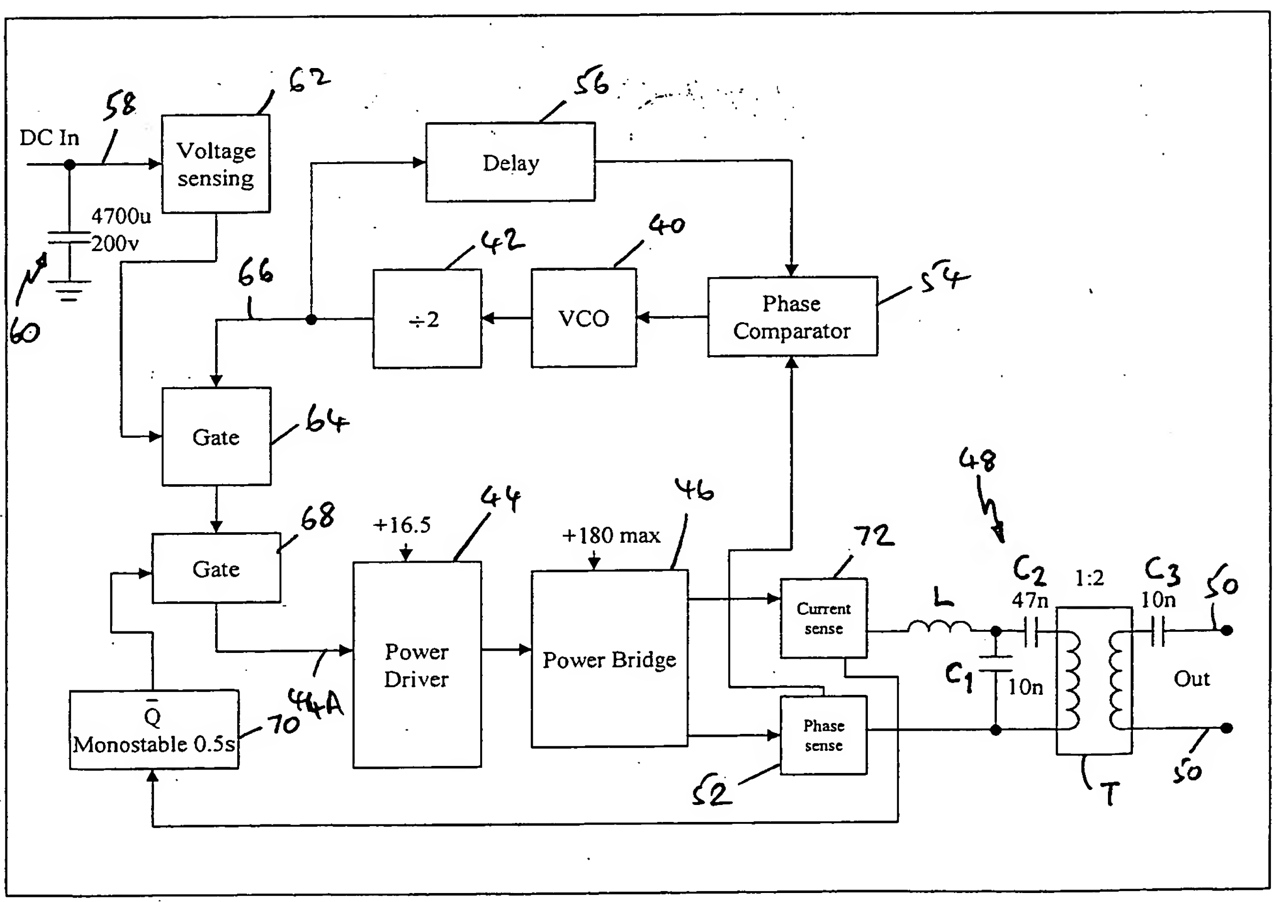

FIG.3

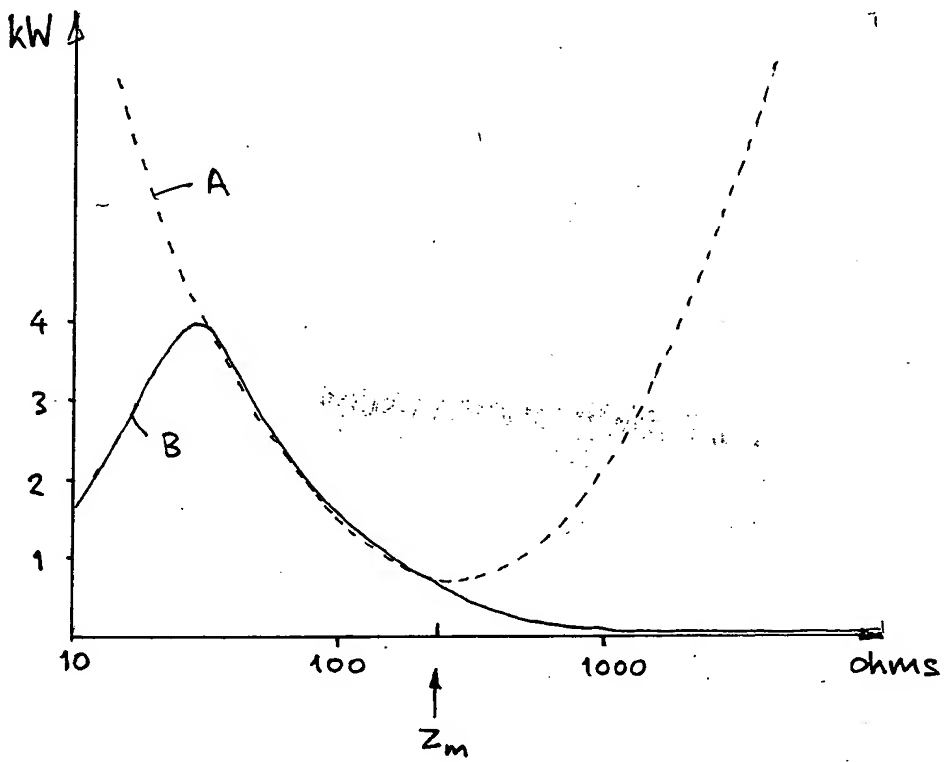

FIG.4